United States
Environmental Protection
Agency

Emergency
Response
Division

Publication 9200.5-105
EPA 540-K-93-003
PB93-963409
July 1993

Understanding Oil Spills and Oil Spill Response

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INTRODUCTION

In an increasingly technological era, we have become more dependent upon petroleum products to help us maintain our high standard of living. Products derived from petroleum, such as heating oil and gasoline, provide fuel for our automobiles, heat for our homes, and energy for the machinery used in our industries. Other products derived from petroleum, including plastics and pharmaceuticals, provide us with convenience and help to make our lives more comfortable.

However, petroleum must be stored and transported, usually in large volumes. As a result of exploration activities, or during storage or transport, oil and other petroleum products are sometimes spilled onto land or into waterways. When this occurs, human health and environmental quality may be at risk. Every effort must be made to prevent oil spills, and to clean them up promptly once they occur.

The purpose of this brochure is to provide information about oil spills. This volume contains individual sections that outline what oil spills are, their potential effects on the environment, how they are cleaned up, and how various agencies prepare for spills before they happen. Details about one oil spill cleanup -- that of the Exxon Valdez spill of March, 1989 -- is provided to offer an example of the complexities that can potentially be involved in oil spill cleanup activities.

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INTRODUCTION

Spilled oil can pose serious threats to the marine environment. The severity of impact of an oil spill depends on a variety of factors, including characteristics of the oil itself. Even large spills of refined petroleum products such as gasoline evaporate quickly and cause only short-term environmental effects. On the other hand, crude oils, heavy fuel oils, and water-in-oil mixtures may cause widespread and long-lasting physical contamination of shorelines. Natural conditions, such as water temperature and weather, also influence the behavior of oil in the marine environment.

PHYSICAL PROPERTIES OF OIL

The term *oil* describes a broad range of natural *hydrocarbon*-based substances and refined petroleum products. (Hydrocarbons are chemical compounds composed of the elements *hydrogen* and *carbon*.) Most refined petroleum products are mixtures of many types of hydrocarbon-based substances. Commonly used products refined from crude oil include fuel oil, gasoline, kerosene, and jet fuel. Each type of crude oil and refined product has distinct physical and chemical properties. These properties affect the way oil will spread and break down, the hazard it may pose to marine and human life, and the likelihood that it will pose a threat to natural and man-made resources.

The rate at which an oil spill spreads will determine its effect on the environment. Most oils tend to spread horizontally into a smooth and slippery surface, called a *slick*, on top of the water. Factors which affect the ability of an oil spill to spread include *surface tension, specific gravity*, and *viscosity*.

- *Surface tension* is the measure of attraction between the surface molecules of a liquid. The higher the oil's surface tension, the more likely a spill will remain in place. If the surface tension of the oil is low, the oil will spread even without help from wind and water currents. Because increased temperatures can reduce a liquid's surface tension, oil is more likely to spread in warmer waters than in very cold waters.

- *Specific gravity* is the density of a substance compared to the density of water. Since most oils are lighter than water, they flat on top of it. However, the specific gravity of an oil spill can increase if the lighter substances within the oil evaporate.

- *Viscosity* is the measure of a liquid's resistance to flow. The higher the viscosity of the oil, the greater the tendency for it to stay in one place. (Honey is an example of a *viscous* liquid.)

THE FATE OF SPILLED OIL

Natural actions are always at work in the marine environment. These can reduce the severity of an oil spill and accelerate the recovery of an affected area. Some natural actions include *weathering, evaporation, oxidation, biodegradation*, and *emulsification.*

- *Weathering* is a series of chemical and physical changes that cause spilled oil to break down and become heavier than water. Wave action may result in natural *dispersion*, breaking a slick into droplets which are then distributed throughout the water column. These droplets can also form a secondary slick or thin film on the surface of the water.

- *Evaporation* occurs when the lighter substances within the oil mixture become vapors and leave the surface of the water. This process leaves behind the heavier components of the oil, which may undergo further weathering or may sink to the bottom of the ocean floor. Spills of lighter refined products such as kerosene and gasoline contain a high proportion of flammable components known as *light ends*. These may evaporate completely within a few hours, causing minimal harm to the environment. Heavier oils leave a thicker, more viscous residue. Wave action from rough seas increases both evaporation and natural dispersion.

- *Oxidation* occurs when oil contacts the water, and oxygen combines with the oil hydrocarbons to produce water-soluble compounds. This process affects oil slicks mostly around their edges. Thick slicks may only partially oxidize, forming *tar balls*. These dense, sticky black spheres may linger in the environment, washing up on shorelines long after a spill.

- *Biodegradation* occurs when micro-organisms such as bacteria feed on oil hydrocarbons. A wide range of micro-organisms is required for a significant reduction of the oil. To sustain biodegradation, nutrients such as nitrogen and phosphorus are sometimes added to the water to encourage the micro-organisms to grow and reproduce. Biodegradation tends to work best in warm water environments.

- *Emulsification* is the process that forms *emulsions*, which are mixtures of small droplets of oil and water. Emulsions are formed by wave action, and they greatly hamper weathering and cleanup processes. Two types of emulsions exist: water-in-oil and oil-in-water. Water-in-oil emulsions are frequently called "chocolate mousse," and they are formed when strong wave action causes water to become trapped inside viscous oil. Chocolate mousse emulsions may linger in the environment for months or even years. Oil and water emulsions cause oil to sink and disappear from the surface, giving the visual illusion that it is gone and the threat to the environment has ended.

An oil slick surrounding a small island

EFFECTS OF OIL ON PLANTS AND ANIMALS

After oil is spilled, the most toxic substances in it evaporate quickly. Therefore, plant, animal, and human exposure to the most toxic substances are reduced rapidly with time, and are usually limited to the initial spill area. Although some organisms may be seriously injured or killed very soon after contact with the oil in a spill (*lethal effects*), non-lethal toxic effects are more subtle and often longer lasting. For example, marine life on reefs and shorelines is at risk of being smothered by oil that washes ashore or of being slowly poisoned by long-term exposure to oil trapped in shallow water or on beaches.

Sensitivity of marine habitats

The marine environment is made up of complex interrelations between plant and animal species and their physical environment. Harm to the physical environment will often lead to harm for one or more species in a food chain, which may lead to damage for other species further up the chain. Where an organism spends most of its time -- in open water, near coastal areas, or on the shoreline -- will determine the effects an oil spill is likely to have on that organism.

In open water, marine organisms such as fish and whales have the ability to swim away from a spill by going deeper in the water or further out to sea, reducing the likelihood that they will be harmed by even a major spill. Marine animals that generally live closer to shore, such as turtles, seals, and dolphins, risk contamination by oil that washes onto beaches or by consuming oil-contaminated prey. In shallow waters, oil may harm sea grasses and kelp beds, which are used for food, shelter, and nesting sites by many different species.

Spilled oil and cleanup operations can threaten different types of marine habitats, with different results.

- *Coral reefs* are important nurseries for shrimp, fish, and other animals as well as recreational attractions for divers. Coral reefs and the marine organisms that live within and around them are at risk from exposure to the toxic substances within oil as well as smothering.

- *Exposed sandy, gravel, or cobble beaches* are usually cleaned by manual techniques. Although oil can soak into sand and gravel, few organisms live full-time in this habitat, so the risk to animal life or the food chain is less than in other habitats, such as tidal flats.

- *Sheltered beaches* have very little wave action to encourage natural dispersion. If timely cleanup efforts are not begun, oil may remain stranded on these beaches for years.

- *Tidal flats* are broad, low-tide zones, usually containing rich plant, animal, and bird communities. Deposited oil may seep into the muddy bottoms of these flats, creating potentially harmful effects on the ecology of the area.

- *Salt marshes* are found in sheltered waters in cold and temperate areas. They host a variety of plant, bird, and mammal life. Marsh vegetation, especially root systems, is easily damaged by fresh light oils.

- *Mangrove forests* are located in tropical regions and are home to a diversity of plant and animal life. Mangrove trees have long roots, called *prop roots*, that stick out well above the water level and help to hold the mangrove tree in place. A coating of oil on these prop roots can be fatal to the mangrove tree, and because they grow so slowly, replacing a mangrove tree can take decades.

Crews work to keep oil from entering a marsh

Sensitivity of marine birds and mammals

An oil spill can harm birds in several ways, by *direct physical contact, toxic contamination*, and *destruction of food sources*.

- *Physical contact* -- When fur or feathers come into contact with oil, they get matted down. This matting causes fur and feathers to lose their insulating properties, placing animals at risk of freezing to death. For birds, the risk of drowning increases, as the complex structure of their feathers that allows birds to float becomes damaged.

- *Toxic contamination* -- Some species are susceptible to the toxic effects of inhaled oil. Oil vapors can cause damage to the animal's central nervous system, liver, and lungs. Animals are also at risk from ingesting oil, which can reduce the animal's ability to eat or digest its food by damaging cells in the intestinal tract. Some studies show that there can be long-term reproductive problems in animals that have been exposed to oil.

- *Destruction of food resources* -- Even species that are not directly in contact with oil can be harmed by a spill. Predators that consume contaminated prey can be exposed to oil through ingestion. Because oil contamination gives fish and other animals unpleasant tastes and smells, predators will sometimes refuse to eat their prey and will begin to starve. Sometimes, a local population of prey organisms is destroyed, leaving no food resources for predators.

SUMMARY

Oil spilled at sea immediately begins to move and weather, breaking down and changing its physical and chemical properties. As these processes occur, the oil threatens surface resources and a wide range of subsurface marine organisms linked in a complex food chain. Many different types of marine habitats exist, with varied sensitivities to the harmful effects of oil contamination and different abilities to recuperate from oil spills. In some areas, habitats and populations can recover quickly. In other environments, however, recovery from persistent or stranded oil may take years.

Sea otters covered with oil

A CHAIN OF EVENTS -- Spilled oil has the potential to affect every level of the marine food chain. Floating oil may contaminate plankton, which includes algae, fish eggs, and the larvae of various invertebrates such as oysters and shrimp. In turn, the small fish that feed on these organisms can become contaminated. Larger animals in the food chain, including bigger fish, bears, and humans, may then eat these contaminated fish. In addition, marine mammals and birds may be exposed directly to oil in the water, which they can ingest or get on their fur or feathers. Spilled oil may also prevent the germination and growth of marine plants and the reproduction of invertebrates either by smothering or by toxic effects.

MECHANICAL CONTAINMENT AND RECOVERY OF OIL FOLLOWING A SPILL

INTRODUCTION

Two major steps involved in controlling oil spills are *containment* and *recovery*. This document outlines some of the techniques and equipment that are used to conduct oil-spill control efforts.

CONTAINMENT

When an oil spill occurs on water, it is critical to contain the spill as quickly as possible in order to minimize danger and potential damage to persons, property, and natural resources. Containment equipment is used to restrict the spread of oil and to allow for its recovery, removal, or dispersal. The most common equipment used to control the spread of oil are floating barriers, or booms.

Containment boom

BOOMS

Containment booms are used to control the spread of oil to reduce the possibility of polluting shorelines and other resources, as well as to concentrate oil in thicker surface layers, making recovery easier. In addition, booms may be used to divert and channel oil slicks along desired paths, making them easier to remove from the surface of the water.

Although there is a great deal of variation in the design and construction of booms, all generally share the following four basic elements:

- An above-water "freeboard" to contain the oil and to help prevent waves from splashing oil over the top of the boom
- A flotation device
- A below-water "skirt" to contain the oil and help reduce the amount of oil lost under the boom
- A "longitudinal support", usually a chain or cable running along the bottom of the skirt, that strengthens the boom against wind and wave action; may also serve as a weight or ballast to add stability and help keep the boom upright

Booms can be divided into several basic types. *Fence booms* have a high freeboard and a flat flotation device, making them least effective in rough water, where wave and wind action can cause the boom to twist. *Round* or *curtain* booms have a more circular flotation device and a continuous skirt. They perform well in rough water, but are more difficult to clean and store than fence booms. *Non-rigid* or *inflatable* booms come in many shapes. They are easy to clean and store, and they perform well in rough seas. However, they tend to be expensive, more complicated to use, and puncture and deflate easily. All boom types are greatly affected by the conditions at sea; the higher the waves swell, the less effective booms become.

Booms can be fixed to a structure, such as a pier or a buoy, or towed behind or alongside one or more vessels. When stationary or moored, the boom is anchored below the water surface.

It is necessary for stationary booms to be monitored or tended due to changes produced by shifting tides, tidal currents, winds, or other factors that influence water depth and direction and force of motion. Boom tending requires round-the-clock personnel to monitor and adjust the equipment.

The forces exerted by currents, waves, and wind may significantly impair the ability of a boom to hold oil. Currents may wash oil beneath a boom's skirt. Wind and waves can force oil over the top of the boom's freeboard or even flatten the boom into the water, causing it to release the contained oil. Mechanical problems and improper mooring can also cause a boom to fail.

While most booms perform well in gentle seas with smooth, long waves, rough and choppy water is likely to contribute to boom failure. In some circumstances, lengthening a boom's skirt or freeboard can aid in containing the oil. However, because they have more resistance to natural forces such as wind, waves, and currents, these oversized booms are more prone to failure or leakage than are smaller ones. Generally, booms will not operate properly when waves are higher than one meter or currents are moving faster than one knot per hour.

Other Barriers: Improvised Booms

When a spill occurs and no containment equipment is available, barriers can be improvised from whatever materials are at hand. Although they are most often used as temporary measures to hold or divert oil until more sophisticated equipment arrives, improvised booms can be an effective way to deal with oil spills, particularly in calm water such as streams, slow-moving rivers, or sheltered bays and inlets.

Improvised booms are made from such common materials as wood, plastic pipe, inflated fire hoses, automobile tires, and empty oil drums. They can be as simple as a board placed across the surface of a slow-moving stream, or a berm built by bulldozers pushing a wall of sand out from the beach to divert oil from a sensitive section of shoreline.

RECOVERY OF OIL

Once an oil spill has been contained, efforts to remove the oil from the water can begin. Three different types of equipment -- *booms, skimmers,* and *sorbents* -- are commonly used to recover oil from the surface.

BOOMS

When used in recovering oil, booms are often supported by a horizontal arm extending directly off one or both sides of a vessel. Sailing through the heaviest sections of the spill at low speeds, a vessel scoops the oil and traps it between the angle of the boom and the vessel's hull. In another variation, a boom is moored at the end points of a rigid arm extended from the vessel, forming a "U"- or "J"-shaped pocket in which oil can collect. In either case, the trapped oil can then be pumped out to holding tanks and returned to shore for proper disposal or recycling.

SKIMMERS

A skimmer is a device for recovery of spilled oil from the water's surface. Skimmers may be self-propelled, used from shore, or operated from vessels. The efficiency of skimmers is highly dependent upon conditions at sea. In moderately rough or choppy water, skimmers tend to recover more water than oil. Three types of skimmers -- *weir, oleophilic*, and *suction* -- are described here. Each type offers advantages and drawbacks depending on the type of oil being cleaned up, the conditions of the sea during cleanup efforts, and the presence of ice or debris in the water.

Weir skimmers use a dam or enclosure positioned at the oil/water interface. Oil floating on top of the water will spill over the dam and be trapped in a well inside, bringing with it as little water as possible. The trapped oil and water mixture can then be pumped out through a pipe or hose to a storage tank for recycling or disposal. These skimmers are prone to becoming jammed and clogged by floating debris.

Oleophilic ("oil-attracting") skimmers use belts, disks, or continuous mop chains of oleophilic materials to blot the oil from the water surface. The oil is then squeezed out or scraped off into a recovery tank. Oleophilic skimmers have the advantage of flexibility, allowing them to be used effectively on spills of any thickness. Some types, such as the chain or "rope-mop" skimmer, work well on water that is choked with debris or rough ice.

Response crew using a suction skimmer ***(Source: U.S. Coast Guard)***

Suction skimmers operate similarly to a household vacuum cleaner. Oil is sucked up through wide floating heads and pumped into storage tanks. Although suction skimmers are generally very efficient, they are vulnerable to becoming clogged by debris and require constant skilled observation. Suction skimmers operate best on smooth water, where oil has collected against a boom or barrier.

SORBENTS

Sorbents are materials that soak up liquids. They can be used to recover oil through the mechanisms of *absorption, adsorption*, or both. *Absorbents* allow oil to penetrate into pore spaces in the material they are made of, while *adsorbents* attract oil to their surfaces but do not allow it to penetrate into the material. To be useful in combatting oil spills, sorbents need to be both oleophilic and hydrophobic ("water-repellant"). Although they may be used as the sole cleanup method in small spills, sorbents are most often used to remove final traces of oil, or in areas that cannot be reached by skimmers. Once sorbents have been used to recover oil, they must be removed from the water and properly disposed of on land or cleaned for re-use. Any oil that is removed from sorbent materials must also be properly disposed of or recycled.

Boom held between two ships as it is moved across oiled water ***(Source: U.S. Coast Guard)***

Sorbents can be divided into three basic categories: *natural organic, natural inorganic*, and *synthetic*. Natural organic sorbents include peat moss, straw, hay, sawdust, ground corncobs, feathers, and other readily available carbon-based products. They are relatively inexpensive and usually readily available. Organic sorbents can soak up between 3 and 15 times their weight in oil, but they do present some disadvantages. Some organic sorbents tend to soak up water as well as oil, causing them to sink. Many organic sorbents are loose particles such as sawdust, and are difficult to collect after they are spread on the water. Adding flotation devices, such as empty drums attached to sorbent bales of hay, can help to overcome the sinking problem, and wrapping loose particles in mesh will aid in collection.

Natural inorganic sorbents include clay, perlite, vermiculite, glass wool, sand, or volcanic ash. They can absorb from 4 to 20 times their weight in oil. Inorganic substances, like organic substances, are inexpensive and readily available in large quantities.

Synthetic sorbents include man-made materials that are similar to plastics, such as polyurethane, polyethylene, and nylon fibers. Most synthetic sorbents can absorb as much as 70 times their weight in oil, and some types can be cleaned and re-used several times. Synthetic sorbents that cannot be cleaned after they are used can present difficulties because arrangements must be made for their temporary storage before they are disposed of.

The following characteristics must be considered when choosing sorbents for cleaning up spills:

- Rate of absorption -- The rate of absorption varies with the thickness of the oil. Light oils are soaked up more quickly than heavy ones.

- Oil retention -- The weight of recovered oil can cause a sorbent structure to sag and deform, and when it is lifted out of the water, it can release oil that is trapped in its pores. Lighter, less viscous oil is lost through the pores more easily than are heavier, more viscous oils during recovery of absorbent materials.

- Ease of application -- Sorbents may be applied to spills manually or mechanically, using blowers or fans. Many natural organic sorbents that exist as loose materials, such as clay and vermiculite, are dusty, difficult to apply in windy conditions, and potentially hazardous if inhaled.

Sorbent squares being used to remove oil from a beach ***(Source: U.S. Coast Guard)***

SUMMARY

The primary line of defense against oil spills is the use of mechanical containment, recovery, and cleanup equipment. Such equipment includes a variety of booms, barriers, and skimmers, as well as natural and synthetic sorbent materials. A key to effectively combatting spilled oil is careful selection and proper use of the equipment and materials most suited to the type of oil and the conditions at the spill site. Most spill response equipment and materials are greatly affected by such factors as conditions at sea, water currents, and wind. Damage to spill-contaminated shorelines and dangers to other threatened areas can be reduced by timely and proper use of containment and recovery equipment.

CLEANING UP AN OIL SPILL: AN EXPERIMENT YOU CAN DO AT HOME

This experiment is designed to help you to understand the difficulties with oil spill cleanups[1]. You will need the following equipment:

- two aluminum pie pans, each half-filled with water
- a medicine dropper full of used motor oil
- cotton balls (use real cotton)
- nylon
- string
- paper towels
- liquid detergent
- feathers

Before you begin, make a list of predictions about the action of oil and water. You might want to answer the following questions in your list:

- What will happen to the oil when you drop it on the water? Will it sink, float, or mix in?
- Which material will clean up the oil in the least amount of time? Cotton, nylon, paper towel, or string?
- How might wind and waves affect the combination of oil and water?

Complete each of the following steps, and observe what happens.

1. Put five drops of motor oil into one of the "oceans" (your aluminum pie pans). Observe the action of the oil and record what happens. Was your prediction correct?

2. One at a time, use the different materials (nylon, cotton, string, and paper towels) to try to clean up the oil from the water, keeping track of the amount of oil each material was able to clean up and how fast it worked. (These materials are what *booms* and *skimmers* are made of.) Which cleaned up the oil the fastest? The best?

3. Add five drops of oil to the second pan. Add five drops of liquid detergent. (This represents the *chemical dispersants*.) Observe what happens. Where do you think the oil would go in the "real" oceans?

4. Dip a feather directly into some oil. What happens to it? How do you think this might affect a bird's behaviors, such as flying, preening, and feeding?

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[1] Used with permission from Jane O. Howard, "Slick Science," *Science and Children*, vol. 27, no. 2 (October 1989).

CHEMICAL AND BIOLOGICAL TREATMENT OF SPILLED OIL

INTRODUCTION

Several methods exist for containing and cleaning up oil spills in the aquatic environment. Mechanical equipment, such as booms and skimmers, is often used to block the spread of oil, concentrate it into one area, and remove it from the water. Chemical and biological treatment of oil can be used in place of, or in addition to, mechanical methods, especially in areas where untreated oil may reach shorelines and sensitive habitats in which cleanup becomes difficult and expensive. This document describes some of the chemical and biological methods that are used by response personnel to contain and clean up oil spills in the aquatic environment.

TYPES OF SUBSTANCES USED

Three types of substances commonly used to contain or clean up an oil spill are (1) *dispersing agents*, (2) *biological agents*, and (3) *gelling agents*.

Dispersing agents

Dispersing agents, also called dispersants, are chemicals that contain *surfactants*, or compounds that act to break liquid substances such as oil into small droplets. In an oil spill, these droplets disperse into the water column where they are subjected to natural processes -- such as wind, waves, and currents -- that help to break them down further. This helps to clear oil from the water surface, making it less likely that the oil slick will reach the shoreline.

The effectiveness of a dispersant is determined by the composition of the oil it is being used to treat, and the method and rate at which the dispersant is applied. Heavy crude oils do not disperse as well as light- to medium-weight oils. Dispersants are most effective when applied immediately following a spill, before the lightest materials in the oil have evaporated.

Environmental factors, including water salinity and temperature and conditions at sea, also influence the effectiveness of dispersants. Studies have shown that many dispersants work best at salinities close to that of normal seawater. The effectiveness of dispersants also depends on water temperature. While dispersants can work in cold water, they work best in warm water.

Some countries rely almost exclusively on dispersants to combat oil spills, because frequently rough or choppy conditions at sea make mechanical containment and cleanup difficult. However, dispersants have not been used extensively in the United States because of difficulties with application, disagreement among scientists about their effectiveness, and concerns that dispersants are toxic.

Helicopters are often used to apply dispersants to large areas of open water

These problems are being overcome, however. New technologies that improve the application of dispersants are being designed. The effectiveness of dispersants is being tested in laboratories and in actual spill situations, and the information collected is being used to help design more effective dispersants. Dispersants used today are much less toxic than those used in the past.

Response person manually applying fertilizer to a "test square" as part of a bioremediation experiment

Biological agents

Biological agents are chemicals or organisms that increase the rate at which natural *biodegradation* occurs. Biodegradation is a process by which *microorganisms* such as bacteria, fungi, and yeasts break down complex compounds into simpler products to obtain energy and nutrients. Biodegradation of oil is a natural process that slowly -- sometimes over the course of several years -- removes oil from the aquatic environment. However, rapid removal of spilled oil from shorelines and wetlands is necessary in order to minimize potential environmental damage to these sensitive habitats.

Bioremediation technologies can help biodegradation processes work faster. Bioremediation refers to the act of adding materials to the environment, such as fertilizers or microorganisms, that will increase the rate at which natural biodegradation occurs. Two bioremediation technologies that are currently being used in the United States for oil spill cleanups are *fertilization* and *seeding*.

Fertilization, also known as nutrient enrichment, is the method of adding nutrients such as phosphorus and nitrogen to a contaminated environment to stimulate the growth of the microorganisms capable of biodegradation. Limited supplies of these necessary nutrients usually control the growth of native microorganism populations. When nutrients are added, the native microorganism population can grow rapidly, potentially increasing the rate of biodegradation.

Seeding is the addition of microorganisms to the existing native oil-degrading population. Sometimes species of bacteria that do not naturally exist in an area will be added to the native population. As with fertilization, the purpose of seeding is to increase the population of microorganisms that can biodegrade the spilled oil.

Gelling agents

Gelling agents, also known as *solidifiers*, are chemicals that react with oil to form rubber-like solids. With small spills, these chemicals can be applied by hand and left to mix on their own. For treating larger spills, the chemicals are applied to the oil, then mixed in by the force of high-pressure water streams. The gelled oil is removed from the water by nets, suction equipment, or skimmers, and is sometimes recovered and reused after being mixed with fuel oil.

Gelling agents can be used in calm to moderately rough seas, since the mixing energy provided by waves increases the contact between the chemicals and the oil, resulting in greater solidification.

There is one drawback to the use of gelling agents. Large quantities of the material must often be applied, as much as three times the volume of the spill. For oil spills of millions of gallons it is impractical to store, move, and apply such large quantities of material.

SUMMARY

Chemical and biological methods can be used in conjunction with mechanical means for containing and cleaning up oil spills. Dispersants and gelling agents are most useful in helping to keep oil from reaching shorelines and other sensitive habitats. Biological agents have the potential to assist recovery in sensitive areas such as shorelines, marshes and wetlands. Research into these technologies continues in the hopes that future oil spills can be contained and cleaned up more efficiently and effectively.

SHORELINE CLEANUP FOLLOWING OIL SPILLS

INTRODUCTION

Shoreline and nearshore areas are important public and ecological resources. However, their cleanliness and beauty, and the survival of the species that inhabit them, can be threatened by accidents that occur during oil drilling and transport activities. Although accidents during these activities are relatively rare, when they do occur oil can be spilled into the world's oceans. Despite the best efforts of response teams to contain this spilled oil, some of it may wash up onto shorelines, into marshes, or into other ecologically sensitive habitats along the water's edge. To help protect these resources from damage and to preserve them for public enjoyment and for the survival of numerous species, cleaning up shorelines following oil spills has become an important part of oil spill response.

SHORELINES: PUBLIC AND ENVIRONMENTAL RESOURCES

Nearshore and shoreline areas serve as homes to a variety of wildlife during all or part of the year. Many bird species build their nests on sand or among pebbles, while others regularly wander the shoreline searching for food. Sea mammals such as elephant seals and sea lions come ashore to breed and bear their pups. Fish such as salmon swim through nearshore zones on their upriver migrations during spawning season, and their offspring swim through these same areas on their trips to the sea in the following year.

Shorelines and nearshore areas also provide public recreation throughout the world. Many beaches are famous for their wide expanses of beautiful sand, while others are admired for their rugged rocky cliffs. Beaches provide opportunities for sports such as swimming, windsurfing and fishing. In developing strategies for cleaning up an oil spill from a shoreline, the characteristics of the shoreline and the natural and recreational resources it provides must be considered.

FACTORS AFFECTING CLEANUP DECISIONS

Whenever possible, control and cleanup of an oil spill at sea begins immediately. If the oil spill can be controlled there is less likelihood that it will reach sensitive habitats near or on shore. If the oil does reach the shore, however, decisions about how best to remove it must be made. These decisions will be based on factors such as the

- type of oil spilled
- geology of the shoreline
- type and sensitivity of biological communities likely to be affected

Each of these factors is described further below.

Type of oil spilled

Lighter oils tend to evaporate and *degrade* (break down) very quickly; therefore, they do not tend to be deposited in large quantities on beaches. Heavier oils, however, tend to form a thick oil-and-water mixture called *mousse*, which clings to rocks and sand. Heavier oils exposed to sunlight and wave action also tend to form dense, sticky substances known as *tar balls* and *asphalt* that are very difficult to remove from rocks and sediments. Therefore, deposits from heavy oils generally require more aggressive cleanup than those from lighter ones.

Geology of the shoreline

Shorelines can vary dramatically in their forms and compositions. Some shorelines are narrow with beaches formed from rounded or flattened cobbles and pebbles; some are wide and covered in a layer of sand or broken shell fragments; and still others are steep cliffs with no beach at all. The composition and structure of the beach will determine the potential effects of oil on the shoreline.

Oil tends to stick to mud and to the surfaces of cobbles and pebbles. It also flows downward in the spaces between cobbles, pebbles, and sand grains, and accumulates in lower layers of beach sediments. Oil that sticks to mud particles suspended in the water column and to cobbles and pebbles on the beach is exposed to the action of sunlight and waves, which helps it to degrade and makes it less hazardous to organisms that come into contact with it. Oil that sticks to rocks and pebbles can be wiped or washed off. Oil that flows onto sandy beaches, however, can "escape" downward into sand, making it difficult to clean up and reducing its ability to degrade.

Type and sensitivity of biological communities

Biological communities differ in their sensitivity to the effects of oil spills and the physical intrusion that may be associated with various cleanup methods. Some ecosystems seem to recover quickly from spills, with little or no noticeable harm, while others experience long-term harmful effects.

Animals, such as elephant seals, that depend on the nearshore or beach environment for breeding and pupping can lose their ability to stay warm in cold water when their skin comes into contact with oil. Birds lose their ability to fly and to stay warm when their feathers are coated with oil, and fish can suffocate when their gills are covered with oil. An oil spill can disrupt a community food chain because it is toxic to some plants, which many organisms depend on for food.

CLEANUP PROCESSES AND METHODS

Both natural processes and physical methods aid in the removal of oil from shorelines. Sometimes, physical methods are used to enhance naturally-occurring processes. An example of a technology that uses both natural processes and physical methods to clean up an oil spill is *bioremediation*, which is described later.

Natural processes

Natural processes that result in the removal of oil from the natural environment include *evaporation, oxidation*, and *biodegradation.*

Evaporation occurs when liquid components in oil are converted to vapor and released into the atmosphere. It results in the removal of lighter-weight substances in oil. In the first 12 hours following a spill, up to 50 percent of the light-weight components may evaporate. Since the most toxic substances in oil tend to be those of lightest weight, this evaporation decreases the toxicity of a spill over time.

Oxidation occurs when oxygen reacts with the chemical compounds in oil. Oxidation causes the complex chemical compounds in oil to break down into simpler compounds that tend to be lighter in weight and more able to dissolve in water, allowing them to degrade further.

Biodegradation occurs when naturally-occurring bacteria living in the ocean or on land consume oil, which they can use to provide energy for their various biological needs. When oil is first spilled, it may be toxic to some bacteria, which makes the initial rate of biodegradation quite slow. As the oil evaporates and the more toxic substances are removed, the population of bacteria grows and biodegradation activity accelerates.

In nature, biodegradation is a relatively slow process. It can take years for a population of microorganisms to degrade most of the oil spilled onto a shoreline. However, the rate at which biodegradation occurs can be accelerated by the addition of nutrients such as phosphorus and nitrogen that encourage growth of oil-degrading bacteria. Biodegradation rates can also be increased by adding more microorganisms to the environment, especially the species that are already used to consuming the type of oil spilled. The use of nutrients or the addition of microorganisms to encourage biodegradation is called *bioremediation*.

Bioremediation has been used with some success in recent oil spill events. Experiments conducted by the U.S. Environmental Protection Agency, Exxon Corporation, and the State of Alaska on cobble beaches contaminated with oil from the 1989 Exxon Valdez spill showed that the addition of nutrients more than doubled the natural rate of biodegradation, and produced no long-term injury to the shoreline or sensitive habitats.

Physical methods

Physical removal of oil from shorelines, and especially beaches, is time-consuming and requires much equipment and many personnel. Methods used to physically clean oil from shorelines include

- wiping with absorbent materials
- pressure washing
- raking or bulldozing

Before physical cleaning methods are used, booms made of absorbent material are often set up in the water along the edge of the beach. Booms prevent oil released during beach cleanup activities from returning to the ocean, and contain the oil so that it can be skimmed from the water for proper disposal.

Wiping with absorbent materials

Materials that are capable of absorbing many times their weight in oil can be used to wipe up oil from contaminated beaches. These materials are often designed as large squares, much like paper towels, or shaped into "mops". The squares or mops are used to wipe the sandy beach or oily rocks during which time the absorbents are filled with as much oil as they can hold.

There are advantages to the use of absorbents. They can be used to clean up any kind of oil on any shoreline that can be reached by response personnel. The use of absorbents is generally not harmful to the beach itself or to the organisms that live on it, and no material is left behind following the cleanup effort. Some sorbents are reusable, reducing the need for disposal after a spill.

However, this method requires the use of a large quantity of material and several personnel. Personnel must wear proper protective clothing to minimize direct contact with the oil as they are removing it. Oil-filled absorbents and protective clothing that are used by response personnel must be properly disposed of following cleanup, which can be costly. In addition, the intrusion of many people onto an isolated beach may disrupt animal behaviors such as breeding or nesting.

Sorbents being used to clean an oiled beach

Pressure washing

Pressure washing involves rinsing oiled beach sands and rocks using hoses that supply low- or high-pressure water streams. Hot or cold water can be used to create these streams. The oil is flushed from the beach into plastic-lined trenches or down to the shoreline, then collected with sorbent materials and disposed of properly.

This method has the advantage of being relatively inexpensive and simple to apply. It requires many personnel and is slow, however. Additionally, high-pressure water streams can dislodge organisms such as algae and mussels from rocks and sediments on which they live, or can force oil deeper into sediments, making cleanup more difficult.

Response crews using high pressure hoses to wash an oil-covered beach
(***Source: U.S. Coast Guard***)

Raking or bulldozing

When oil moves downward into the sands or between pebbles and cobbles on a shoreline, it becomes more difficult to remove. If the oil has moved downward only a short distance, tilling or raking the sand can increase evaporation of the oil by increasing its exposure to air and sunlight. If the oil has penetrated several inches into the sand, bulldozers may be brought in to remove the upper layers of sand and pebbles. This allows the oil to be exposed so it can be collected and removed from the site, washed with pressure hoses, or left to degrade naturally.

Raking and bulldozing are simple methods for helping to remove oil that might otherwise escape into sediments. However, these methods can disturb both the natural shape of the shoreline and the plant and animal species that live on and in the beach sediments. In addition, the use of bulldozers requires specially trained operators who can maneuver them without damaging the beach unnecessarily; raking and tilling are time-consuming and require many personnel.

DISPOSAL OF OIL AND DEBRIS

Cleanup from an oil spill is not considered complete until all waste materials are disposed of properly. The cleanup of an oiled shoreline can create different types of waste materials, including liquid oil, oil mixed with sand, and tar balls. Oil can sometimes be recovered and reused, disposed of by *incineration,* or placed in a *landfill*. States and the Federal government strictly regulate the disposal of oil.

Reuse or recovery of oil requires that the oil be processed and separated from the other materials such as water that are mixed in with it. The recovered oil can then be blended with other fuels for use in power plants or boilers.

Incineration uses extremely high temperatures to convert compounds such as oil into carbon dioxide and water. When a mobile incinerator is used at a remote spill site, the need for transporting large volumes of oiled wastes to distant disposal sites is eliminated. This can be a practical and efficient method to manage large volumes of waste generated during a cleanup. Because incineration can potentially produce air pollution, it is important that it be used in strict compliance with air pollution laws.

Landfilling is another method of disposing of oiled debris. The oil is mixed with chemicals such as calcium oxide ("quicklime") that stabilizes the oil and makes it less able to leak into groundwater or soils. Mixtures of quicklime and oil must sometimes be taken to specially designed landfills for disposal.

SUMMARY

Cleaning shorelines after an oil spill is a challenging task. Factors that affect the type of cleanup method used include the type of oil spilled, the geology of the shoreline, and the type and sensitivity of biological communities in the area. Natural processes such as evaporation, oxidation, and biodegradation help to clean the shoreline. Physical methods, such as wiping with sorbent materials, pressure washing, and raking and bulldozing can be used to assist these natural processes. Oil collected during cleanup activities must be reused or disposed of properly, using such methods as incineration or landfilling. Choosing the most effective yet potentially least damaging cleaning methods helps to assure that the natural systems of shorelines and the recreational benefits they offer will be preserved and protected for future generations.

RESCUING BIRDS AND MAMMALS FROM OIL SPILLS

INTRODUCTION

When an oil spill occurs, birds and marine mammals are often injured or killed by oil that pollutes their habitat. Without human intervention, many distressed birds and animals have no chance of survival.

Unfortunately, rescuing wildlife is a difficult, time-consuming task. Following the Exxon Valdez oil spill in March, 1989, the bodies of over 36,000 birds and 1,000 sea otters were recovered in Prince William Sound, Alaska. Scientists suspect that many more actually perished as a result of the spill.

HUMAN INTERVENTION

Many government agencies and private organizations help to rescue marine animals and birds that have been exposed to oil pollution. When an oil spill occurs, there is often a plan to help these groups cooperate to save as many animals as possible. While the government is responsible for animal rescue efforts, many private organizations assist in rescuing injured wildlife. Before any person or organization can handle or confine birds or mammals for rescue, however, they must get special permits that are issued by State and Federal officials.

If oil is spilled into a marine environment, the first step to stop the crisis is to control the release and spread of oil at its source. This prevents any additional oil exposure to wildlife and coastal areas. At the same time, efforts are made to keep animals away from possible contamination. Devices such as propane scare cans, floating dummies and helium-filled balloons are often used to scare animals away from oily areas, particularly birds.

RESCUING BIRDS

For areas that have been polluted by oil, rescuers must capture birds that have been affected as quickly as possible in order to save them. Two-way radio communications are often used to help rescuers locate oily birds. Once birds have been captured, they are taken immediately to treatment centers where they are given medical treatment and cleaned.

If treatment centers are not available nearby, temporary facilities must be built in local warehouses or other large buildings that offer electricity, hot water, and ventilation. The International Bird Rescue Research Center of Berkeley, California has designed a bird cleaning facility that can be operated from a trailer, so that a truck can bring the facility to the scene of an accident immediately.

Human handling injured wildlife ***(Source: U.S. Coast Guard)***

Minimizing stress is critical for ensuring that captured birds survive. Rescue parties usually will contact rehabilitation workers even before they arrive, to make sure that they are prepared to care for the captured birds immediately. This ensures that the birds are treated as quickly as possible.

Once a bird has been brought to a rehabilitation center, certain basic procedures are followed. First, oil is flushed from its eyes and intestines. Heavily oiled birds are wiped with absorbent cloths to remove patches of oil. Rehabilitation workers also conduct an initial examination to detect broken bones, cuts, or other injuries. Stomach-coating medicines (such as Pepto Bismol™) may be administered orally to prevent additional absorption of oil inside the bird's stomach. The bird is then warmed and placed in a quiet area. Curtains are often hung to limit its contact with people.

Birds in recovery pens after oil has been removed from their feathers

How Oil Affects Birds

Birds that are exposed to oil are affected both internally and externally. The most serious threat birds face is the destruction of their feathers, or plumage. Birds rely on their plumage to protect them in cold environments. Strong, outer feathers, known as *contour* feathers, help birds to fly, float, and keep warm in the water. Soft, inner feathers, known as *down*, also provide insulation that is necessary for survival. When a bird's feathers are covered by oil, the bird loses its ability to fly, float, and maintain a normal body temperature. This means the bird cannot get food or escape from its predators.

Birds are also at risk from swallowing oil, inhaling oil fumes, or absorbing it through their skin. Oil can cause kidney or liver damage, digestive problems, eye damage, and other disorders that can cause pneumonia.

Birds also suffer from stress caused by the destruction to their habitat. In fact, stress is a leading cause of death in birds exposed to oil. As a bird becomes cold and loses its ability to float, it may go into a panic, causing the bird to exhaust itself.

Nutrition is essential for the recovery of oiled birds. Wild birds will generally learn to feed themselves from pans or other containers as soon as they begin to feel healthy. In many cases, however, the birds must be force-fed until they are able to feed on their own.

After a bird is alert, responsive, stable and its body's fluid balance restored to normal, detergent is gently stroked into its feathers to remove the oil. An oiled bird may require three or more washings to remove the oil entirely.

After its feathers are completely rinsed, the bird is placed in a clean holding pen lined with sheets or towels. The pen is warmed with heat lamps, and hung with curtains to minimize human contact. If behavior appears normal and a bird's condition remains stable, it is allowed to swim. The bird then begins to preen and realign its feathers to restore them to their original structure, helping the bird to become waterproof again.

Before a bird can be considered for release, it must "pass" the waterproofing test. That is, it must demonstrate buoyancy (the ability to float) and water-repellency (the ability to keep water away from its body). Once a bird passes this test, it is slowly exposed to temperatures comparable to outside weather. Its weight and muscle structure should be average for its species, and it should show no signs of disease. Rehabilitated birds are banded by the U.S. Fish and Wildlife Service, and are released early in the day to an appropriate habitat.

MARINE MAMMAL RESCUE AND CLEANING

Two primary groups of marine animals may be affected during an oil spill. The first group, *pinnipeds*, includes animals such as walruses, harbor seals, and sea lions. These animals are quite large, and rely on blubber under their skin to stay warm. Harbor seal mothers give birth on isolated beaches and small rocky islands. Newborn pups are not yet protected by a layer of blubber, and do not enter the water until a few days after birth. Some scientists are concerned that when a seal pup's protective fur coat becomes oiled, its warming qualities are reduced, increasing the likelihood of death from exposure. When these animals are seriously distressed, they are handled by marine mammal stranding networks, such as the Marine Mammal Center in San Francisco, California.

The second group of fur-bearing marine mammals includes sea otters and fur seals. These animals do not have a layer of blubber, but instead rely on their thick fur coats to maintain warmth. If the coat becomes dirty through contact with oil or other polluting substances, its protection may be lost, and the animal will become chilled in icy waters. Sea otters, in particular, groom themselves extensively and are at risk from swallowing toxins.

The Hubbs Research Center, in San Diego, California, specializes in mammal rescue efforts. The Center employs experienced animal handlers to ensure the best treatment of stricken animals. Other animal welfare organizations, such as Friends of the Sea Otter and local Societies for the Prevention of Cruelty to Animals, provide marine mammal rehabilitation sites.

Specific techniques are employed by the Hubbs Center and other organizations to help oiled marine mammals to recover. After an animal is captured and transported to a marine rehabilitation facility, it is checked for hypothermia and dehydration, then prepared for cleaning. The otter is lightly sedated during the washing process, which is usually done by a team of two. One restrains the animal and the other washes it with a mild detergent. Once rinsed, the otter is hand-rubbed with towels and dried with hand dryers. Through its natural grooming process, the otter preens itself, distributing an oil-like fluid produced by glands in its skin. In about seven days, the otter's fur will regain its water-repellency.

Otter being towel-dried following removal of oil from its fur

During the recuperation process, an otter's body temperature and eating habits are monitored. It is fed a variety of its favorite foods, including fish, squid, shrimp, and scallops. As its health improves, the animal is moved to a holding tank. Slowly, it is introduced to its natural habitat. Often, an otter will try to return to a habitat that is still contaminated. For this reason, released otters are tagged with tracking devices. Some are held for longer periods of time in order to give cleanup crews additional time to remove more oil from the area.

After the Exxon Valdez oil spill, otter rehabilitation and pre-release centers were built in Valdez, Seward, and Homer, Alaska. These facilities remained in operation until September, 1989. The three centers treated a total of 357 otters, and released 197 into Prince William Sound and along the Kenai Peninsula. Because of concerns for their health, an additional 24 adult otters were sent to various seaquariums. In addition, 13 otter pups, most of which were born in captivity, were transferred to seaquariums because they were too young to be released.

Several other organizations devote their energies to the rehabilitation of birds following oil spills. Tri-state Bird Rescue and Research, Inc., of Wilmington, Delaware, is often called to help with East Coast spills. On the West Coast, the International Bird Rescue Research Center, located in Berkeley, California, is well-known for its work. Washington Oiled Bird Rescue, in Washington State, is also devoted to the rehabilitation of oiled birds.

These organizations follow similar techniques to recover and rehabilitate oiled birds. Periodic hands-on exercises are conducted to provide workers with sufficient spill-related experience.

SUMMARY

Many lessons about the care and treatment of oiled birds and animals have been learned through experience with recent oil spill incidents. First, the need for immediate response is essential for rescuing wildlife. Second, personnel training is needed. The rehabilitation of oiled wildlife is a complex medical and technical procedure, and volunteers must be properly trained. Training workshops, which involve more than 200 hours of work, are available through the organizations cited above. Third, a commitment must be made to reclaim oiled wildlife using proven, documented procedures, and avoiding shortcuts. Finally, open communication with other response agencies is crucial for any wildlife rescue operation to be successful.

FOR MORE INFORMATION ABOUT BIRD REHABILITATION, CONTACT:

Marjorie Gibson
International Bird Rescue Research Center
699 Potter Street
Berkeley, CA 94710

Dr. Heidi Stout/ Lynne Frink
Tri-State Bird Rescue and Research, Inc.
110 Possum Hollow Road
Newark, DE 19711

FOR MORE INFORMATION ABOUT MAMMAL REHABILITATION, CONTACT:

American Cetacean Society
Box 2639
San Pedro, CA 90731

Center for Marine Conservation
312 Sutter Street, Suite 316
San Francisco, CA 94108

Defenders of Wildlife
1244 19th Street, NW
Washington, DC 20036

Friends of the Sea Otter
P.O. Box 221220
Carmel, CA 93922

Monterey Bay Aquarium
886 Cannery Row
Monterey, CA 93940

National Wildlife Federation
1412 16th Street, NW
Washington, DC 20036

FEDERAL AND STATE AGENCIES RESPONSIBLE FOR ANIMAL RESCUE FOLLOWING SPILLS

Commandant (G-MEP)
U.S. Coast Guard
2100 2nd Street, SW
Washington, DC 20593
(202) 267-2611

Department of the Interior
U.S. Fish and Wildlife Service
1849 C Street, NW
Washington, DC 20240
(202) 208-5634

NOAA/HMRAD
7600 Sand Point Way, NE
Bin C15700
Seattle, WA 98115
(206) 526-6317

Alaska Department of Environmental Conservation
410 Willoughby Ave.
Juneau, AK 99801-1795
(907) 465-5000

PREPARING FOR OIL SPILLS: CONTINGENCY PLANNING

INTRODUCTION

Oil spills are, unfortunately, common events in many parts of the United States. Most of them are accidental, so no one can know when, where, or how they will occur. Spills can happen on land or in water, at any time of day or night, and in any weather conditions. Preventing oil spills is the best strategy for avoiding potential damage to human health and the environment from exposure to oil. However, once a spill occurs, the best approach for containing and controlling it is to respond quickly and in a well-organized manner.

THE ROLE OF CONTINGENCY PLANS

In order to respond rapidly and successfully to an oil spill, personnel responsible for containing and cleaning up the spill must know the steps that need to be followed during and after the spill. *Contingency plans* are documents that describe information and processes for containing and cleaning up an oil spill that occurs in a defined geographic area. A defined area can be relatively small, such as a piece of property that has oil storage tanks on it, or it can be large, involving the land and waters within and between several states.

A *contingency plan* is like a "game plan," or a set of instructions that outlines the steps that should be taken before, during, and after an emergency. When used properly by trained response personnel, a contingency plan can provide many benefits such as allowing oil response efforts to proceed smoothly and effectively, minimizing danger to cleanup personnel, reducing overall costs of cleanup by avoiding unnecessary effort, and assuring that sensitive habitats are protected.

ELEMENTS OF A CONTINGENCY PLAN

At first glance, a well-designed contingency plan may appear complicated because it provides many details about all the steps involved in preparing for, and responding to, an oil spill. However, a well-designed contingency plan should be easy to follow. Despite their differences, though, all contingency plans usually contain three major elements:

- Spill scenarios
- Background information
- Response actions

Each of these elements is described briefly below.

Spill Scenarios

It is impossible to know when an oil spill is going to happen and how much oil is likely to be spilled. Sometimes oil spills occur in places that are easy for response personnel to get to, while at other times they occur in remote spots that are difficult to bring equipment into. Some spills are very small and easily controlled, while others are very large and difficult to manage.

Different combinations of the factors that can affect the ability of response personnel to contain and clean up an oil spill, such as weather conditions, geographic isolation, and spill size, are called *scenarios*. Private companies and local, state and federal agencies design their contingency plans to reflect several different scenarios. In order to develop these scenarios, the following information may be collected:

- types of oils frequently stored in or transported through that area

- locations in which oil is stored in large quantities or through which traffic of oil tankers is high

- locations of sensitive habitats and human populations

- extreme weather conditions that might occur in the area during different times of the year

Contingency plans are designed to help response personnel to be prepared for the kind of spill that is "most likely" for a particular place.

On rare occasions, however, a spill occurs in severe weather conditions, or is much larger or more difficult to get to, than those that are most likely. To prepare for these unusual but severe incidents, contingency plans also include "worst case" scenarios. A worst case scenario, for example, might assume that a large quantity of very dense, heavy oil has spilled during a dark, stormy night, close to vacation homes and extremely sensitive habitats along the shoreline. By being prepared for the worst case scenario, response personnel will also be prepared for less severe incidents.

Background Information

This section of a contingency plan provides information to personnel involved in cleaning up a spill to help them make reasonable, well-informed choices about how to contain and clean up a spill when it occurs. Such background information might include

- names and phone numbers of individuals who work with private companies or local, state and federal agencies who are responsible for helping with oil spill cleanup efforts

- descriptions of physical, chemical and biological techniques that can be used to contain or clean up an oil spill

- lists of response equipment available in the area

- lists of oil-sensitive habitats and wildlife resources that must be protected

- description of the communications system that will be used to coordinate the various personnel and agencies involved in the control and cleanup effort

Response Actions

A carefully designed contingency plan will describe major actions that need to be undertaken when a spill occurs. These actions should take place immediately following a spill so as to minimize hazards to human health and the environment. Actions to be taken during a spill that should be described in the contingency plan include

- notifying all private companies or government agencies that are responsible for the cleanup effort

- getting trained personnel to the site quickly

- defining the size, position, and content of the spill, its direction and speed of movement, and its likelihood of hitting sensitive habitats

- assuring the safety of all response personnel

- stopping the flow of oil from the ship, truck, or storage facility, if possible

- containing the spill to a limited area

- removing the oil

- disposing of the oil once it has been removed from the water or land

EXAMPLES OF CONTINGENCY PLANS

Many different kinds of contingency plans exist for dealing with oil spills. Some contingency plans are designed to help deal with an oil spill that might occur at a very specific place, such as an oil storage or refining facility. Others are designed to help to deal with spills that might occur anywhere within a large geographic region. In fact, the federal government has designed a National plan that establishes the process for dealing with any spill that occurs in the United States.

Facility Contingency Plans

Every facility in the United States that stores or refines oil products, whether owned by a private company or operated by a government agency, is required to develop a plan for dealing with an accidental release of oil on its property. These contingency plans typically contain information such as

- the company's or agency's policies for dealing with spills
- job descriptions for various personnel within the company or agency and their responsibilities for dealing with a spill
- proper procedures for notifying and alerting employees and response personnel
- rules and regulations to be followed to control and clean up spills

Regional Contingency Plans

Federal and state government agencies with responsibility for protecting the environment develop contingency plans for specific geographic regions of the United States (see map). These plans include detailed information about resources (such as equipment and trained response personnel) available from the federal government and the states or commonwealths within particular regions. They describe the roles and responsibilities of each state and federal agency during a spill, and how agencies will respond if they are called upon in an emergency. These plans also describe how two or more regions might interact, such as when a spill occurs in a river that flows between regions, to assure that a spill is controlled and cleaned up in a timely and safe manner.

Regional plans are often brought into action when facilities are unable to handle spills on their own. In such situations, special teams -- called Regional Response Teams, or RRTs -- may be called upon to provide technical advice as well as cleanup equipment and specially trained personnel. RRTs conduct training exercises to test the abilities of federal and state agencies to respond quickly and to work together to control and clean up spills. These exercises help states and the federal government to identify problems with their oil spill response plans so that the plans can be improved if necessary.

The National Contingency Plan

The U.S. Environmental Protection Agency (EPA) has designed a plan, called the National Contingency Plan or NCP, to ensure that resources and expertise of the federal government would be available for those relatively rare, but very serious, oil spills that require a national response. This plan was designed primarily to assist with coordinating the various federal agencies that are responsible for dealing with oil spill emergencies.

The NCP was developed and is continuously updated through efforts of the National Response Team (NRT), which is composed of representatives from 14 different federal agencies, including EPA, the U.S. Coast Guard, and the Federal Emergency Management Agency. Although the NRT does not respond directly to incidents, it stands ready to offer technical advice and coordination assistance if requested during an incident. It also provides information about emergency training exercises to local and state governments, assists in the design of international contingency plans, and recommends improvements to Regional Contingency Plans.

IMPROVING CONTINGENCY PLANS

After an oil spill has been controlled and cleaned up, the companies as well as the local, state and federal agencies that were involved in the emergency assess the usefulness of their contingency plans. Information gathered during the assessment, such as problems that had not been considered in the original plan, and the successes or failures of cleanup techniques used, will be used in a revised contingency plan. This information will also be shared with private companies and states, regions, and federal agencies so that they too may learn from oil spills to improve their contingency plans.

SUMMARY

Planning for an oil spill emergency helps to minimize potential danger to human health and the environment by assuring a timely and coordinated response. Well-designed local, state, regional and national contingency plans can assist response personnel in their efforts to contain and clean up oil spills by providing information that the response teams will need before, during, and after spills occur. Because the approaches and methods for responding to oil spills are constantly evolving, and each oil spill provides an opportunity to learn how to better prepare for future incidents, contingency plans are also constantly evolving and improving -- assuring increased protection to human health and the environment from these accidents.

RESPONDING TO OIL SPILLS: THE NATIONAL RESPONSE SYSTEM

INTRODUCTION

When a major oil spill occurs in any navigable waters in the United States (U.S.), coordinated teams of local, state and national personnel are called upon to help contain the spill, clean it up, and assure that damage to human health and the environment is minimized. Without careful planning and clear organization, efforts to deal with large oil spills could be slow, ineffective, and potentially harmful to response personnel and the environment.

The system that has been established in the U.S. for organizing responses to major oil spills is called the National Response System. This document describes the origins of the National Response System and outlines the responsibilities of the teams and individuals who plan for and respond to major oil spills in navigable waters.

THE NATIONAL RESPONSE SYSTEM

On March 18, 1967, a 970-foot oil tanker, the Torrey Canyon, ran aground 15 miles off the western coast of England, spilling 117,000 tons of crude oil that eventually washed up onto the popular resort beaches of England and France. Although the U.S. had not yet experienced a spill of this size in its coastal waters, the federal government began to question its ability to respond to such spills if they occurred here. As a result, in 1968 several Federal agencies developed a plan, now called the National Oil and Hazardous Substances Pollution Contingency Plan, or National Contingency Plan (NCP) for short, that would bring together federal agencies with various kinds of expertise to respond to oil spills when they occur. The NCP, which was made into law in 1973, established the National Response System, a network of individuals and teams from local, state and federal agencies who share expertise and resources to assure that oil spill control and cleanup activities are timely and efficient, and that they minimize threats to human health and the environment.

The three major components of the National Response System are the (1) *On-Scene Coordinator, (2) National Response Team,* and (3) *Regional Response Teams.* The National Response System is activated when the *National Response Center* receives notification of an oil spill.

The National Response Center

The National Response Center, located in Washington, D.C., is one of the first organizations to be notified when an oil spill occurs. It is staffed by officers and marine science technicians from the U.S. Coast Guard, and serves as the national communications center responsible for notifying the On-Scene Coordinator (OSC) whose job it is to oversee cleanup efforts at the spill site.

The On-Scene Coordinator

The On-Scene Coordinator (OSC) is a federal official who is responsible for all federal government efforts to contain, remove, and dispose of spilled oil in a major incident. This official is also responsible for coordinating federal efforts with, and providing support and information to, local, state and regional response communities.

The OSC is a representative of one of two federal agencies: the U.S. Coast Guard (USCG) or the U.S. Environmental Protection Agency (EPA). The USCG has designated 48 OSCs; EPA has designated 145 OSCs. When a spill occurs in coastal waters, the OSC is the local USCG Port Commander. When a spill occurs inland, a regional EPA official is assigned as the OSC.

The OSC is responsible for four main tasks during an oil spill response: (1) assessment, (2) monitoring, (3) response assistance, and (4) reporting.

Assessment

Assessment involves evaluating the size and nature of a spill, its potential hazards, the resources needed to contain and clean it up, and the ability of the responsible party or local authorities to handle the incident. The OSC typically conducts these activities at the beginning of a response. The results of the assessment are used to determine the need for personnel, equipment, and other resources to promptly and effectively combat the spill.

Monitoring

Monitoring comprises those activities taken to ensure that the actions being taken to control and clean up a spill are appropriate. All spills of a legally defined minimum size must be monitored by an OSC, even though most spills are small and are cleaned up by the responsible party or local fire or police departments. Monitoring can be conducted from the site when necessary, or from an agency office if the situation appears to be under control.

Response Assistance

Once a spill has been assessed, the OSC determines whether federal assistance will be necessary to help control and contain the spill. If the OSC decides that federal assistance is required, the OSC will obtain needed resources such as personnel and equipment. If sufficient resources are not available at or near the spill site, the OSC can secure them using a special fund -- the Oil Spill Liability Trust Fund (see box)-- which has been established for this purpose. This assistance is intended to ensure that oil spill cleanups will not be hindered by a lack of personnel or equipment.

The Oil Spill Liability Trust Fund

The company or individual responsible for an oil spill (known as a responsible party, or RP) has legal liability, to a defined maximum amount, for expenses related to containment and cleanup of the spill. However, when the RP is unable to pay for cleanup, funds from the Oil Spill Liability Trust Fund can be used to pay for removal costs and/or damages resulting from discharges of oil into U.S. waters. This Trust Fund, created by Congress in 1990, is administered by the U.S. Coast Guard (USCG), and is based on a five-cent per barrel fee on imported and domestic oil. It also provides funds for research into and development of oil spill cleanup technologies. In 1990, $25 million per year was authorized to the USCG for its operating expenses for oil spill cleanup efforts. Another $30 million per year (until the end of 1992) was provided to establish the National Response System, and nearly $28 million per year is made available for research and development programs.

Reporting

Reporting on oil spill response actions provides information that is useful for designing or improving spill response plans. The NCP requires that the OSC report all activities that take place during and after a spill. For example, following a spill, the OSC is required to file a summary report that outlines the actions taken to remedy the spill and the level of assistance provided by local, state, and federal agencies. These reports can be used to identify problem areas and can be shared with other agencies who may make recommendations for improvement.

The National Response Team

The National Response Team (NRT) is an organization composed of fifteen federal agencies, each of which has responsibilities in environmental areas and expertise in various aspects of emergency response to pollution incidents. Although the NRT does not respond directly to incidents, it is responsible for three major activities related to managing oil spill response: (1) distributing information, (2) planning for emergencies, and (3) training for emergencies.

Distributing information

The NRT is responsible for ensuring that information about oil spills -- technical, financial, and operational -- is available to all members of the team. This information is collected primarily by NRT committees whose purpose is to focus attention on specific issues, then collect and disseminate information on those issues to other members of the team.

Planning for emergencies

The NRT ensures that the roles of federal agencies on the Team for oil spill emergency response are clearly outlined in the National Contingency Plan. After a major spill event, the effectiveness of the response is carefully assessed by the NRT. The NRT may use information gathered from the assessment to make recommendations for improving the National Contingency Plan and the National Response System.

The NRT may be asked to help Regional Response Teams (see below) develop Regional Contingency Plans. The NRT also reviews these plans to ensure that they comply with federal policies on emergency response.

Training for emergencies

One important aspect of any emergency response is preparedness, which is best developed by training. Although most training is actually performed by state and local personnel, the NRT develops training courses and programs, coordinates federal agency training efforts, and provides information to regional, state and local officials about training needs and courses.

Supporting RRTs

The NRT supports Regional Response Teams (RRTs) by reviewing Regional Contingency Plans and assuring that they are consistent with national policies on oil spill cleanup. The NRT also supports RRTS by monitoring and assessing RRT effectiveness during an oil spill cleanup activity. The NRT may ask an RRT to focus on specific lessons learned from a specific incident and to share those lessons with other members of the National Response System. In this way, the RRTs can improve their own Regional Contingency Plans while helping to solve problems that might be occurring elsewhere within the National Response System.

Regional Response Teams

There are thirteen Regional Response Teams (RRTs) in the U.S., each representing a particular geographic region (including the Caribbean and the Pacific Basin). RRTs are composed of representatives from field offices of the federal agencies that make up the NRT as well as state representatives. The four major responsibilities of RRTs are (1) response, (2) planning, (3) training, and (4) coordination.

Response

RRTs provide a forum for federal agency field offices and state agencies to exchange information about their abilities to respond to OSCs' requests for assistance. As with the NRT, RRT members do not respond directly to spills but may be called upon to provide technical advice, equipment, or manpower to assist with a response.

Planning

Each RRT develops a Regional Contingency Plan to ensure that during an actual oil spill the roles of federal and state agencies are clear. Following an oil spill, the RRT reviews the OSCs' reports to identify problems with the Region's response to the incident and improves the plan as necessary.

Training

Federal agencies that are members of the RRTs provide simulation exercises of Regional plans to test the abilities of federal, state and local agencies to coordinate their responses to oil spills. Any major problems identified as a result of these exercises may be addressed and changed in the Regional Contingency Plans so the same problems do not arise during an actual incident.

Coordination

The RRTs are responsible for identifying the resources available from each federal agency and state in their regions. Such resources include equipment, guidance, training, and technical expertise for dealing with oil spills. When there are too few resources in a Region, the RRT can request assistance from federal or state authorities to ensure that sufficient resources will be available during a spill. This coordination by the RRTs assures that resources are used as wisely as possible, and that no Region is lacking what it needs to protect human health and the environment from the effects of an oil spill.

SUMMARY

The National Response System is the mechanism established by the federal government to respond to discharges of oil into navigable waters of the United States. This system functions through a cooperative network of federal, state and local agencies. The primary mission of the system is to provide support to state and local response activities.

The major components of the National Response System are the On-Scene Coordinator, the National Response Team, and the thirteen Regional Response Teams. These individuals and teams work together to develop detailed Contingency Plans to outline responses to oil spill emergencies before they occur, and to develop or engage in training that prepares for actual emergencies. During oil spill events, they cooperate to ensure that all necessary resources such as personnel and equipment are available, and that containment, cleanup, and disposal activities are timely, efficient, and effective. It is through this cooperation that the National Response System protects human health and the environment from potential harm from oil spills in navigable waters.

NATIONAL AND REGIONAL RESPONSE TEAM MEMBER AGENCIES

One representative from each of the following fourteen agencies sits on the NRT. One representative from each Regional office of these agencies and representatives from each state within the Region sit on the RRTs.

Environmental Protection Agency
Coast Guard
Department of Agriculture
Department of Commerce
Department of Defense
Department of Energy
Department of Health and Human Services
Department of the Interior
Department of Justice
Department of Labor
Department of State
Department of Transportation
Federal Emergency Management Agency
General Services Administration
Nuclear Regulatory Commission

RESPONSE TO OIL SPILLS: THE EXXON VALDEZ

INTRODUCTION

On March 24, 1989, shortly after midnight, the oil tanker Exxon Valdez struck Bligh Reef in Prince William Sound, Alaska, spilling more than 11 million gallons of crude oil. (See Figure 1.) The spill was the largest in U.S. history and tested the abilities of local, national, and industrial organizations to prepare for, and respond to, disasters such as these. Many factors complicated the cleanup efforts following this spill. The size of the spill and its remote location, accessible only by helicopter or boat (see Figure 2), made government and industry efforts difficult and tested existing plans for dealing with such an event.

The spill posed threats to the delicate food chain that supports Prince William Sound's commercial fishing industry. Also in danger were ten million migratory shore birds and waterfowl, hundreds of sea otters, dozens of other species such as harbor porpoises and sea lions, and several varieties of whales.

THE INCIDENT

The two-year-old oil tanker Exxon Valdez, with a capacity of 1.46 million barrels (62 million gallons) of oil, was the newest and largest of Exxon's 19-ship fleet. On the evening of March 23, 1989, 1.26 million barrels (54 million gallons) were loaded onto the ship in Valdez, Alaska. The ship left the port at 9:10 p.m., bound for Long Beach, California.

Chunks of ice from the nearby Columbia Glacier were sitting low in the water, so the ship's captain tried to turn into an empty inbound shipping channel to avoid them. The ship was moving at approximately 12 miles per hour when it struck the rocks of Bligh Reef in Prince William Sound. The underwater rocks tore huge holes in eight of the vessel's eleven giant cargo holds, releasing a flood of oil into the Sound. More than 11 million gallons of oil spilled within five hours of the event. Seven hours after the spill was reported, the resulting oil slick was 1,000 feet wide and four miles long.

In addition to the spilled oil, there were other immediate dangers. About 80 percent of the ship's oil cargo remained on board; the ship was resting in an unstable position and in danger of capsizing. Removing the remaining oil from the ship and cleaning the spilled oil were top priorities.

THE RESPONSE

Since the incident occurred in open navigable waters, the U.S. Coast Guard's On-Scene Coordinator had authority for all activities related to the cleanup effort. Once he was notified of the spill, he immediately closed the Port of Valdez to all traffic. A Coast Guard investigator, along with a representative from the Alaska Department of Environmental Conservation, visited the scene of the incident to assess the damage caused by the spill. By noon on Friday, March 25th, the Alaska Regional Response Team was brought together by teleconference, and the National Response Team was activated soon thereafter. The National team is based in Washington, D.C. and is composed of representatives from fourteen different Federal agencies, with either the Environmental Protection Agency or the U.S. Coast Guard taking primary responsibility for coordinating oil-spill cleanup activities.

Alyeska, the association that represents seven oil companies who operate in Valdez, including Exxon, first assumed responsibility for the cleanup. Alyeska operates the pipeline and terminal at Valdez and is responsible for carrying out plans for oil-spill emergencies. Alyeska opened an emergency communications center in Valdez shortly after the spill was reported and set up a second operations center in Anchorage, Alaska.

The On-Scene Coordinator, in cooperation with the Exxon Corporation, established several goals for the response. The most important goal was to prevent additional spilling of oil. Because the Exxon Valdez was unstable and in danger of capsizing, the 43 million gallons of oil still onboard the tanker threatened the environmentally-sensitive Sound. The first priority was to protect four fish hatcheries that were threatened by the spill. In addition, there were concerns about the safety of response personnel, since highly flammable and toxic fumes made response actions difficult.

Numerous equipment problems slowed down the response to the spill. Alyeska had mechanical containment equipment available such as booms, which are floating mechanical barriers that are designed to stop the spread of oil, but there were not enough of them to contain an 11 million gallon spill. Because of the remote location of the spill, equipment had to be moved over great distances to reach the accident scene. The barge used by Alyeska's response team had been stripped for repairs, and was therefore not immediately available for use. It took ten hours to prepare and load the barge, and another two hours to reach the Exxon Valdez.

In addition, the remote location of the incident presented many logistical problems. Because the spill site was located two hours by boat from the port of Valdez, every task was time-consuming. The response had to be staged from mobile platforms, and equipment had to be air-dropped or delivered by boat.

Other problems became apparent as the emergency teams began to arrive to help with the cleanup. Only limited lodging was available in Valdez, a small village of only 4,000 people. The small airstrip at Valdez could not handle large planes carrying the cleanup equipment. These planes were forced to land in Anchorage, a nine-hour drive from Valdez. The Federal Aviation Administration, the agency responsible for all air traffic control, had to set up a temporary tower to manage increased flights to the area.

At the start of the spill, necessary communications between response personnel were difficult because there was limited phone service in Valdez. The Coast Guard On-Scene Coordinator was the only person with a direct telephone line out of the community. The lack of phone lines delayed cleanup teams from being able to request the resources they needed, and it took time for the phone company to increase the number of phone lines. Radio communication was also troublesome. The large numbers of boats working the area resulted in multiple simultaneous radio transmissions, and the mountainous terrain made radio communication difficult. The Coast Guard established a news office and requested more communications staff, because numerous national media representatives were arriving in Valdez every day.

On the second day of the spill, Exxon assumed responsibility for the cleanup and its costs. Exxon activated its emergency center in Houston, Texas, which sent equipment to stabilize the ship. The company directed another ship, the Exxon Baton Rouge, to remove the remaining oil from the stricken Valdez.

In taking responsibility for the cleanup operations, Exxon set out to address the problems mentioned earlier. The company opened a communications network that allowed information about the spill and the cleanup efforts to be shared with state and federal government officials, private company representatives, and others who were interested in the events surrounding the spill. The company, in cooperation with the U.S. Coast Guard, installed four weather stations around Prince William Sound to provide the weather forecasts that were critical to planning cleanup efforts. A refueling station for helicopters was set up in Seward, Alaska. More than 274 tons of additional equipment, including skimmers, booms, and dispersants arrived at the site by the fourth day.

Hundreds of people were brought to the area to help conduct the cleanup effort within two days of the spill. More than 1,000 Coast Guard personnel, along with employees of the National Oceanic and Atmospheric Administration, the Fish and Wildlife Service, and the Environmental Protection Agency helped with the response. Nine additional Coast Guard cutters and eight aircraft were brought to the scene. Specialists from the Hubbs Marine Institute of San Diego, California, set up a facility to clean oil from otters, and the International Bird Research Center of Berkeley, California established a center to clean and rehabilitate oiled waterfowl.

THE CLEANUP

Three methods were tried in the effort to clean up the spill:

- burning
- chemical dispersants
- mechanical cleanup

A trial burn was conducted during the early stages of the Exxon Valdez spill. A fire-resistant boom was placed on tow lines, and the two ends of the boom were each attached to a ship. The two ships, with the boom between them, moved slowly through the main portion of the slick until the boom was full of oil. The ships then towed the boom away from the slick and the oil was ignited. The fire did not endanger the main slick or the Exxon Valdez because of the distance separating them. Because of unfavorable weather conditions, however, no additional burning was attempted in this cleanup effort.

Soon after the spill, dispersants were sprayed from helicopters. Mechanical cleanup was started using booms and skimmers.

The use of dispersants proved to be controversial. Alyeska had less than 4,000 gallons of dispersant available at its terminal in Valdez, and no application equipment or aircraft.

A private company applied dispersants on March 24 with a helicopter and dispersant bucket. Because there was not enough wave action to mix the dispersant with the oil in the water, the Coast Guard representative at the site concluded that the dispersants were not working.

Skimmers, devices that remove oil from the water's surface, were not readily available during the first 24 hours following the spill. Thick oil and heavy kelp tended to clog the equipment. Repairs to damaged skimmers were time-consuming. Transferring oil from temporary oil storage vessels into more permanent containers was also difficult because of the oil's weight and thickness. Continued bad weather slowed down the recovery efforts.

Efforts to save delicate areas were begun early in the cleanup. Sensitive environments were identified, defined according to degree of damage, and then ranked for their priority for cleanup. Seal pupping locations and fish hatcheries were given highest importance, and for these areas special cleaning techniques were approved. Despite the identification of sensitive areas and the rapid start-up of shoreline cleaning, however, wildlife rescue was slow. Adequate resources for this task did not reach the accident scene quickly enough. Through direct contact with oil or because of a loss of the their food resources, many birds and mammals died.

THREE YEARS AFTER THE SPILL

During the three years after the Exxon Valdez oil spill, cleanup and environmental restoration of the affected shorelines and islands continues. The cost of the cleanup has amounted to billions of dollars, and the cost of legal settlements has resulted in millions more.

On June 12, 1992 the U.S. Coast Guard announced that the cleanup activities should end. Although the cleanup activities have ceased, there are still pools of oil left in some areas where it is assumed that the harm caused to the ecosystem by the oil is not greater than the benefits to be gained from further cleanup.

The Exxon Valdez incident and the environmental impact caused by the spill attracted the attention of national political, scientific, and environmental interests. The scientific groups include those from Exxon Corporation and the U.S. Environmental Protection Agency that got involved in efforts to use experimental technologies such as bioremediation to clean up the spill. The National Oceanic and Atmospheric Administration was involved in providing weather forecasts for Prince William Sound. This allowed the cleanup team to know what type of cleanup technology would be compatible with the changing weather conditions in the Sound. A Valdez trustee council was born, which is organizing a meeting about oil spills to attract more scientific research papers from studies on the Exxon Valdez incident. This council is made up of representatives from numerous federal and Alaskan state agencies that deal with environmental issues.

The Exxon Valdez incident also prompted the U.S. government to require the U.S. Environmental Protection Agency and the U.S. Coast Guard to strengthen their regulations on oil tank vessels and oil tank owners and operators under an environmental law known as the *Oil Pollution Act of 1990*. As of July 17, 1992, all tank vessels of 20,000 tons or greater are required to carry special equipment that will enable the vessel captain and the vessel traffic center in Valdez to communicate better for safer sailing through that area.

Restoration projects to bring back natural conditions of the affected areas are just beginning. On September 30, 1991, an agreement was reached between Exxon Corporation, the state of Alaska, and the Federal government. As a result of this agreement, Exxon Corporation agreed to pay $900 million for environmental restoration.

SUMMARY

The Exxon Valdez incident increased public awareness about the risks involved in the transport of oil. It also revealed many weaknesses in the abilities of state, federal, and industry officials to plan for and respond to such a disaster. The remote location of the spill and a lack of necessary equipment added to response problems.

Prevention of spills is the first line of defense, and the oil industry has taken steps to reduce the risks of oil spills. Once a spill occurs, however, improved response coordination between federal, state, and local authorities should produce more rapid cleanup actions. A program to provide better training of emergency response personnel is being prepared, and safety issues are being addressed. Beach-cleaning techniques that are more effective and less labor-intensive are being developed. Studies of the long-term environmental effects of oil spills and their influence on food chains in the ocean and on land are now underway. The costs of cleanup activities, ecosystem restoration, and legal settlements of oil spills are so high that the best strategy is to work to prevent them.

PAGE OF PHOTOGRAPHS OF EXXON VALDEZ AND SPILL CONTROL-RELATED ACTIVITIES

GLOSSARY

Asphalt: A brown to black residue formed from weathered petroleum products, consisting chiefly of a mixture of hydrocarbons; varies in texture from hard and brittle to plastic.

Biodegradation: The breaking down of substances by microorganisms, which use the substances for food and generally release harmless byproducts such as carbon dioxide and water.

Bioremediation: The act of adding nutrients or microorganisms to the environment to increase the rate at which biodegradation occurs.

Boom: A temporary floating barrier used to contain an oil spill.

Dispersion: The spreading of oil on the water's surface and, to a lesser degree, into the water column.

Emulsification: The formation of a mixture of two liquids, such as oil and water, in which one of the liquids is in the form of fine droplets and is dispersed in the other.

Evaporation: The physical change by which any substance is converted from a liquid to a vapor or gas.

Hydrocarbons: A large class of organic compounds containing only carbon and hydrogen; common in petroleum products.

Hydrophobic: Not easily wet by water.

Incineration: The destruction of wastes by burning at high temperatures.

Mousse: A thick, foamy oil-and-water mixture formed when petroleum products are subjected to mixing with water by the action of waves and wind.

Oil: As commonly used, a naturally-occurring mixture of hydrocarbons and other substances typically used as fuels or refined for use in a variety of commercial products.

Oleophilic: Having a strong affinity for oils.

Oxidation: A chemical reaction that occurs when a substance is combined with oxygen; may lead to degradation or deterioration of the substance.

Seeding: The addition of microorganisms to the environment; used in bioremediation.

Skimmers: Devices used to remove oil from the water's surface.

Slick: A thin film of oil on the water's surface.

Sorbents: Substances that take up and hold water or oil.

Solidifiers: Substances that can be added to liquid oil to make the oil "harden" into solid substances that can either be picked up from the water's surface or left to sink to the ocean bottom.

Specific gravity: The ratio of the density of a substance to the density of water.

Surface tension: The attractive force exerted upon the surface molecules of a liquid by the molecules beneath the surface. When oil is spilled on water, this tension makes the oil behave as a continuous thin sheet that is difficult to separate or break up.

Surfactant: A substance that breaks oil into small droplets. This helps to increase the surface area of the oil spill, which increases the rate at which the oil can be degraded or weathered into less toxic substances.

Tar balls: Dense, black sticky spheres of hydrocarbons; formed from weathered oil.

Viscosity: Resistance to flow. Substances that are extremely *viscous* do not flow easily.

Weathering: Action of the elements on a substance, such as oil, that leads to disintegration or deterioration of the substance.

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